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A Reconfiguration Study for the NavLab II Mobile Robot

R. Craig Coulter & George G. Mueller

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The Robotics Institute
Carnegie Mellon University
Pittsburgh, Pennsylvania 15213

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R. Craig Coulter and George G. Mueller

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The NavLab II mobile robot was built approximately three years ago to serve as a general purpose autonomous navigation testbed. Since that time, a number of sensors and sensor support equipment has been added to the vehicle, increasing the vehicle power draw and weight and decreasing the system's overall performance. This report describes a power and weight distribution study that was done as a precursor to a redesign of the vehicle configuration. The engineers used these power consumption measurements and the vehicle weight distribution in the design of the next version of the NavLab II.

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Abstract

The NavLab II mobile robot was built approximately three years ago to serve as a general purpose autonomous navigation testbed. Since that time, a number of sensors and sensor support equipment has been added to the vehicle, increasing the vehicle power draw and weight and decreasing the system's overall performance. This report describes a power and weight distribution study that was done as a precursor to a redesign of the vehicle configuration. The engineers used these power consumption measurements and the vehicle weight distribution in the design of the next version of the NavLab II.

1.0 Introduction

The NavLab II mobile robot was built approximately three years ago to serve as a mobile testbed for high-speed onroad and off-road navigation. Over the last three years, a number of modifications have been made to the vehicle to enhance sensor modality, which has led to a series of weight and power draw increases.

This report examines the current mechanical and electrical configuration of the vehicle. We have systematically measured the weight and powerdraw of every significant component in the vehicle with the aim of determining how our resources are distributed. We proposed to determine where the significant power and weight expenditures lay as a basis for redesigning the system. This report presents the power and weight distribution for the NavLab II mobile robot, along with a set of general conclusions that serve to motivate the need for a reconfiguration effort.

1.1 Summary

This report concludes the following:

- That the power system is over-powered for the current and foreseeable applications.
- That the vehicle is over weight.
- That it is very difficult to diagnose system problems due to a lack of documentation.
- That the wiring system is unnecessarily complicated.
- That similar, if not superior subcomponent performance can be achieved using fewer, smaller, or lighter components.

This report makes the following general recommendations:

- That the Staget be replaced with a small camera and pan / tilt system.
- That one rear passenger station be removed.
- That the current computing cage be abandoned in favor of a lighter, insulated cage.
- That the roof-top air conditioner be replaced by a smaller, in-vehicle system.
- That one generator and one UPS be removed.
- That the remaining generator be moved inside the vehicle.
- That the wiring and cabling be charted before reconfiguration.

2.0 Vehicle System Specifications

2.1 Mission Statement

The NavLab II mobile robot is a navigation laboratory; its fundamental purpose is to support research in autonomous navigation. The Unmanned Ground Vehicles (UGV) group has two distinct subsets of navigation: on-road and off-road. These two research modes distinguish themselves one from the other as follows:

- Off-road navigation is performed in rugged, often dirty terrain at relatively low speeds. The vehicle is expected to have high geometric mobility, to mount and cross significant obstacles, and to be highly stable. The emphasis in this arena is on terrainability. Sensor modalities may vary, though missions are principally performed using ladar.
- On-road navigation is principally performed on the highway, or on city streets. The vehicle is expected to operate at near constant speeds between 10 and 70 miles per hour. The emphasis is on constant speed, non-aggressive driving. The preferred sensor is the camera.

2.2 System Specifications

The vehicle, as a hardware system, provides the following functions:

- Perception sensors and sensor support.
- Software development computing.
- Control computing.
- Position estimation sensing.
- Power support.
- Environmental support. (cooling, lighting, etc.)

It is left to the designers to provide these faculties in whatever manner that they see fit, however it is expected that their design will be optimized in some respect. In the case of mobile robotics, the optimization standards are usually cost and mobility. Thus the basic task that confronts us is to provide perception and computing at the lowest possible cost (in dollar, time and mobility).

3.0 Current Power and Weight Budget

A power and weight study of the current vehicle configuration provides a benchmark against which proposed configurations may be measured. In this study, the vehicle configuration is divided into the following subcategories:

- Monitors.
- Sparc Computing (both processor boards and associated support boards.)
- Controller Computing (all boards used in the VME cage.)
- Sensors
- Amps and Actuators
- Power Supplies
- Structure

3.1 Monitors

The vehicle is currently equipped with three types of monitors. There are three color Sun monitors, two located in the rear passenger area and a third located at the driver's console. At the moment, one of the rear monitors is removed. Each of the rear passengers has a large Sony monitor for the display of camera / ladar images. The driver has a miniaturized version.

Table 1: Monitors

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
Color Sun Monitor #1	55	N/A	360	132
Color Sun Monitor #2	55	N/A	360	132
Color Sun Monitor #3	55	N/A	360	132
Large Sony Monitor #1	[30]	N/A	99	74
Large Sony Monitor #2	[30]	N/A	99	74
Miniature Sony Monitor	17	36	[36]	33
TOTAL	242	N/A	1314	577

3.2 Sparc Computing

The main vehicle processing is supplied by three Sparcstation 2 engines. In support are a number of boards, listed in the following table.

Table 2: Sparc Computing Cage

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
Sparc 2: Moe	2	20	N/A	[20]
Sparc 2: Larry	2	20	N/A	[20]
Sparc 2: Curly	2	20	N/A	[20]
Disk Drives / CD / TAR	10	N/A	N/A	25
Larry Master	1	25	35	[30]
M68000 Ironics	1	N/A	N/A	15
Erim Interface	1	N/A	N/A	[20]
Matrox (B&W)	1	N/A	N/A	16
Curly Master	1	25	35	[30]
Matrox (R)	1	N/A	N/A	16
Matrox (G)	1	N/A	N/A	16
Matrox (B)	1	N/A	N/A	16
TOTAL	24	N/A	N/A	[244]

3.3 Controller Hardware

The current controller configuration is comprised of eight main boards, plus a ninth board used in conjunction with the Litton INS. The following table breaks down the hardware configuration:

Table 3: Controller Cage

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
M68000 Master	1	25	35	[30]
M68000 Slave	1	25	35	[30]
Creonics MCC #1	1	10	N/A	[10]

Table 3: Controller Cage

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
Creonics MCC #2	1	10	N/A	[10]
Creonics MCC #3	1	10	N/A	[10]
A/D	1	12.5	N/A	[12.5]
DIO	1	8	N/A	[8]
Ethernet	1	22	N/A	[22]
Litton INS unit (with power supply)	40	N/A	N/A	[520]/[200]
TOTAL	48	N/A	N/A	[652.5] / [332.5]

3.4 Sensors and Sensor Support Equipment

The vehicle supports three perception sensor modalities: ladar (ERIM[1]), camera and FLIR, though the last is currently not often used. The remainder of the equipment listed in the following table is used to display camera images (video switchers) or to position the FLIR, Schwartz laser rangefinder and camera (Staget[2] and supporting electronics).

Table 4: Sensors and Sensor Support Equipment

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
Sony Controller	[10]	N/A	N/A	26
Video Encoder	[8]	N/A	N/A	54
Video Switcher (R)	8.8	N/A	N/A	0
Video Switcher (L)	8.8	N/A	N/A	0
Video Switcher (Rack 1)	8.8	17	20	17
Video Switcher (Rack 2)	8.8	17	20	14
Video Switcher (Rack 3)	8.8	17	20	14
Video Switcher (Rack 4)	8.8	17	20	14

1. ERIM: Engineering Research Institute of Michigan; the manufacturer of the laser rangefinder.
2. The Staget is an inertially stabilized pointing platform that is used to aim the camer, laser rangefinder and FLIR.

Table 4: Sensors and Sensor Support Equipment

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
Camera	[10]	N/A	N/A	26
Staget Communications	33	N/A	N/A	inc. below
Staget Electronics	40	N/A	N/A	inc. below
ERIM	75	N/A	N/A	300
Staget	317	N/A	N/A	336
TOTAL	545.8	N/A	N/A	801

3.5 Amps and Actuators

The physical motions of the vehicle are carried out by three actuators mounted to the steering wheel, the throttle plate and the brake, respectively. Each actuator requires an amplifier to amplify the motion control signal. The power for the amps and actuators is provided by the vehicle's altenator, which is entirely independent of the power system in question. We are thus only concerned with the component's weight.

Table 5: Amps and Actuators

Item	Weight (lbf)
Steering Amp	1
Steering Motor	8.1
Throttle Amp	1
Throttle Motor	2
Brake Amp	1
Brake Motor	8
TOTAL	21.1

3.6 Power Supplies

The vehicle has seven power supplies. One is dedicated to the Staget and ERIM. The Acopian principally serves the INS and is a replacement for the Lambda. The remainder of the power supplies reside in the top of the electronics cage.

Table 6: Power Supplies

Item	Weight (lbf)	Specified Average Power (W)	Specified Maximum Power (W)	Measured Power (W)
Staget / Erim	{7}	N/A	N/A	20
Acopian 28 VDC	5.5	N/A	N/A	30
Lambda 24 VDC	7.5	N/A	N/A	23
Cage #1	{5}	N/A	N/A	N/A
Cage #2	{5}	N/A	N/A	N/A
Cage #3	{5}	N/A	N/A	N/A
Cage Lambda	{10}	N/A	N/A	N/A
Total	{45}	N/A	N/A	73

3.7 Structure

Supporting structure is necessary for several components. This listing neglects such items as passenger seats, roofing structural supports, and other items.

Table 7: Structure

Item	Weight (lbf)
Cage, Driver side	180
Cage Passenger side	180
Generator Support (D)	{150}
Generator Support (P)	{150}
A/C Roof Cover	50
TOTAL	710

3.8 Air Conditioning

Air conditioning is provided for both the passengers and for one of the computing cages. The passenger air conditioning is powered by the vehicle's engine. Only the computing cage is cooled through the auxiliary power. The

current vehicle air conditioning system is rated at 13,100 BTU/hr. It is comprised of a roof mounted compressor and two remote evaporator units, each of which is mounted to the back of one of the electronics cages. At this time only one of the evaporators is used as only one cage is cooled.

Table 8: Air Conditioning

Item	Weight (lbf)
A/C Evaporator #1	60
A/C Evaporator #2	60
A/C Compressor	{100}
TOTAL	220

3.9 Power Generation, Conditioning and Battery Back-up.

Vehicle power is provided by two outboard gasoline generators. Each generator supplies two legs of 110 VAC power, each rated to 2.5 KVA. Power conditioning and battery back-up is provided by two Mesta UPS units, each of which is rated for 5000 KVA through-put. Fully charged battery storage will provide 5KVA of power for 7 minutes at maximum load.

Table 9: Power

Item	Weight (lbf)
Generator #1	178.6
Generator #2	178.6
UPS #1	325
UPS #2	325
TOTAL	1007.2

3.10 Configuration Totals

Table 10: Current Configuration Total

Subcomponent	Weight (lbf)	Max Power (W)	Ave. Power (W)
Monitors	242	N/A	580
Sparc Computing	24	N/A	244
Controller Computing	48	332.5	652.5
Sensors	545.8	N/A	801
Amps and Actuators	21.1	N/A	N/A
Power Supplies	{45}	N/A	73
Structure	710	N/A	N/A
Air Conditioning	220	6985	1800
Power	1007.2	N/A	N/A
TOTAL	2863.1	N/A	4150.5

The vehicle was weighed by a PennDOT team. The results are summarized in the following table.

Table 11: Vehicle Weight Distribution

(lbf)	Front Axel	Rear Axel
Left Side	1800	3300
Right Side	1650	3450
Total	3450	6750

The total vehicle weight is the sum of the front and rear axel weights, which is 10,200 lbf.

As delivered, the vehicle weight specifications are as follows:

Table 12: Specified Max Weights

(lbf)	Curb	GVW
Front Axel	3235	3650
Rear Axel	3945	4950
Total	7180	8600

Comparing the specifications with the current vehicle weight. the front axel is still 200 lbf under the GVW, but the rear axel is 1800 lbf overweight. As a check against the weight estimate, adding the total curb weight to the weight estimate of the current configuration produces a total of 10,020, which is within 2% of the measured weight of 10,200. The HMMWV center of mass is reported to be 71.2 inches behind the front axel. From the measured weights, it can be shown that the center of mass has moved to 86 inches behind the front axel, a shift of 14.8 inches.

3.11 Conclusions

From the power and weight study, we can conclude the following:

- That the vehicle is currently 18.6% overweight.
- That the system currently uses only 41.5% of the available electrical power.
- That air conditioning the rack constitutes 43.4% of the power draw.
- Although the air conditioning steady state can be provided, the start up spike is well outside of the power system's capability.
- Sensors constitute 19% of the retrofit weight.
- Structure constitutes 25% of the retrofit weight.
- Power generation equipment constitutes 33% of the retrofit weight.

3.12 General Comments

It is currently difficult to perform standard maintenance tasks or system upgrades on this mobile robot for a number of reasons. The cages were not designed for ease of maintenance or replacement of parts. Very little of the wiring system is labelled or documented. There is also little or no documentation to allow the quick ordering of a replacement parts.

It is our recommendation that during the upcoming reconfiguration the following things be done:

- Simplify the cabling; this is time consuming and boring, but it must be done.
- Emplace simple diagnostics that read out things like power draw for important components.
- Force the development of a complete set of vehicle documentation, to include a master parts list and a master wiring schematic.